# 12.0 SUMMARY, FINDINGS, CONCLUSIONS & RECOMMENDATIONS

## 12.1 Summary

This Groundwater Evaluation was designed to enhance understanding of the role groundwater plays in the eutrophication processes reducing lake clarity. This Groundwater Evaluation is a portion of the Lake Tahoe Framework Implementation Report that Congress directed the Corps to complete. The State of Nevada, the State of California, TRPA, and a coalition of non-government organizations identified the effort presented in this Groundwater Evaluation as a critical missing element needed to present alternatives for improvement of environmental quality. The primary concerns affecting lake clarity identified by Basin stakeholders are nutrient and sediment loading to the lake. This study provides an evaluation of the nutrient loading only, specifically phosphorous and nitrogen, as contributed by groundwater flowing into Lake Tahoe. Within that context, the major objectives of this study were to:

1. Determine an estimate of nutrient loading to the lake through groundwater on a regional basis,
2. Identify known and potential sources of nutrients to groundwater, and
3. Identify nutrient reduction alternatives that could be used in the basin.

This Groundwater Evaluation is a portion of the Lake Tahoe Framework Implementation Report being completed by the U.S. Army Corps of Engineers (Corps) at the direction of Congress. The Framework Report will present alternatives for improvement of environmental quality at Lake Tahoe by enhanced implementation of projects. Basin stakeholders identified the effort presented in this groundwater evaluation as a critical missing element to presenting any alternatives for improvement of environmental quality. A summary of recommendations from this study will be included in the report to Congress.

This study was based on the evaluation of information from other reports, previous investigations, data collected by various agencies and personal communication with many stakeholders in the basin. This report represents the results of an in-depth review of existing reports and did not include any field work. However, based on the findings of this report, it is recommended that additional fieldwork be conducted in the future.

The nutrient loading estimate provides information as to whether groundwater is a significant source of nutrients to Lake Tahoe. It was important to local stakeholders to understand the regional loading estimates, rather than a whole lake loading estimate. For this reason, the estimates were separated into five regions. The five regions included South Lake Tahoe/Stateline, East Shore, Incline Village, Tahoe Vista/Kings Beach and Tahoe City/West Shore.

Known and potential sources of nutrients to groundwater were also evaluated as part of this study. This portion of the study is integral in determining any alternatives that could be used to reduce the loading from groundwater. The key sources evaluated are fertilized areas, sewage, infiltration basins and urban infiltration.

The initial evaluation of potential nutrient reduction alternatives is presented. This evaluation is a first step in identifying various technologies that may be applied across the basin and the prioritization of this application relative to the remediation of other sources. These technologies provide stakeholders a start in determining the appropriate alternatives for areas of concern.

Identifying the data gaps was a fundamental part of this study. They provide the basis for the recommendations provided in this evaluation. The data gaps identified while performing the groundwater evaluation are summarized in Table 12-1. Each is prioritized to highlight the relative importance of each to the nutrient loading estimates and the evaluation of the most significant sources. Each data gap is identified with a priority 1, 2 or 3. Priority 1 represents the most important data gaps. Additional information on how to resolve each of these data gaps are included in the summary and conclusions for each region (Sections 4 – 8).

**Table 12-1. Prioritization of Data Gaps**

| Priority | Data Gap | Resolution |
|---|---|---|
| 1 | Tahoe City/West Shore and Tahoe Vista/Kings Beach: Inadequate hydraulic conductivity data and geologic definition. | Geologic investigations will provide a more complete definition of the subsurface composition and better estimates of hydraulic conductivity which is critical to the groundwater discharge estimate. |
| 1 | Tahoe City/West Shore, Tahoe Vista/Kings Beach and East Shore: Data is sparse defining the geometry of the sedimentary fill below the length of shoreline. | Investigations of the depth and shape of the fill deposits will provide better data to estimate groundwater discharge. |
| 1 | Tahoe City/West Shore: Groundwater monitoring wells are not screened to represent different depths or placed to monitor upgradient land uses. | Groundwater monitoring wells which are screened at different depths and placed near the lake to represent upgradient land uses will provide more accurate nutrient concentrations for use in the loading estimates. |
| 1 | Tahoe Vista/Kings Beach: Data is unavailable to determine if the former treated wastewater ponds in the North Tahoe Regional Park are a significant source. | Investigation of the former treated wastewater ponds in the North Tahoe Regional Park will determine if this is a major source of nutrients in the region. |

| Priority | Data Gap | Resolution |
|---|---|---|
| 1 | East Shore: Little data is available to define the geology of the region. | Define the hydrologic significance of the weathered zone, how groundwater interacts and flows through this zone, and to what extent do fractures play in groundwater flow to supply better information for groundwater discharge estimates. |
| 1 | Tahoe City/West Shore: An evaluation of the groundwater/stream interaction is lacking. This is most important in the North Tahoe City, Ward Valley, and Meeks Bay subregions. | Groundwater/stream interaction studies will help define where wells should be placed to monitor groundwater discharge to streams vs. the lake. |
| 1 | Incline Village: Data is unavailable to determine if the Village Green infiltration basin is a significant source of nutrients to the lake. | Investigate the effects of the Village Green infiltration basin to groundwater to determine if it is a major source. |
| 2 | Incline Village: Data is unavailable to determine if the former treated wastewater pond and infiltration trenches located along Mill Creek are a significant source of nutrients to the lake. | Study the residual effects of the former treated wastewater pond and infiltration trenches located along Mill Creek to conclude if it is a major source of nutrients. |
| 2 | South Lake Tahoe/Stateline, Tahoe Vista/Kings Beach, Tahoe City/West Shore, Incline Village & East Shore: Little is understood regarding how different land use types affect groundwater nutrient loading. | Specific land use types should be targeted for additional monitoring to better understand each as a contributor. Examples include residential areas that are fertilized vs. those that prefer natural vegetation and ball fields and urban parks. |
| 2 | South Lake Tahoe/Stateline: Little is understood regarding how dry wells affect groundwater nutrient loading. | Investigate the effects of dry wells to groundwater to conclude if it is a major source of nutrients. |
| 2 | Incline Village: Groundwater monitoring wells are not screened to represent different depths or placed to monitor upgradient land uses | Groundwater monitoring wells which are screened at different depths and placed near the lake to represent upgradient land uses will provide more accurate nutrient concentrations for use in the loading estimates. |

| Priority | Data Gap | Resolution |
|---|---|---|
| 2 | Incline Village. Inadequate hydraulic conductivity data and geologic definition. | Geologic investigations will provide a more complete definition of the subsurface composition and better estimates of hydraulic conductivity which is critical to the groundwater discharge estimate. |
| 2 | Incline Village: Data is sparse defining the geometry of the sedimentary fill below the length of shoreline. | Investigations of the depth and shape of the fill deposits will provide better data to estimate groundwater discharge. |
| 3 | South Lake Tahoe/Stateline (Emerald Bay to Taylor Creek Subregion): Groundwater elevation data is lacking in the region. | This region should be targeted for additional groundwater level measurements to better define the gradient for the region which will improve the groundwater discharge estimate. |
| 3 | South Lake Tahoe/Stateline (Emerald Bay to Taylor Creek Subregion): Inadequate hydraulic conductivity data and geologic definition. | Geologic investigations will provide a more complete definition of the subsurface composition and better estimates of hydraulic conductivity which is critical to the groundwater discharge estimate. |
| 3 | Incline Village & Tahoe Vista/Kings Beach: An evaluation of the groundwater/stream interaction is lacking. | Groundwater/stream interaction studies will help define where wells should be placed to monitor groundwater discharge to streams vs. the lake. |
| 3 | Incline Village: The effects of faults on groundwater movement is not understood. | Define the extent fractures play in groundwater flow to supply better information for groundwater discharge estimates. |
| 3 | South Lake Tahoe/Stateline: The groundwater wells are not currently placed to properly evaluate all the potential sources or nutrient concentration with depth. | Groundwater monitoring wells which are screened at different depths and placed near the lake to represent upgradient land uses will provide more accurate nutrient concentrations for use in the loading estimates. |

## 12.2 Findings

The major findings of this study are statements of fact or of the best available information at the time of this study.

- A comprehensive management strategy for groundwater monitoring and reporting is not currently in place. No consistent means of collecting data is in place for the multitude of organizations performing groundwater investigation in the Lake Tahoe Basin.

- Groundwater as a source of nutrients to the lake has not been an area of concern until recently. There have been minimal studies done to monitor groundwater quality and determine if it is a potential source of nutrients to Lake Tahoe.

- Little investigation of the subsurface geology has been conducted in the basin. Most of the geologic investigation has occurred in the South Lake Tahoe area. The remainder of the basin geology is little understood.

- A majority of the groundwater wells and stream gage stations have not been surveyed.

- The nutrients analyzed by agencies throughout the basin are not consistent.

- The groundwater wells used to monitor nutrients have been selected from wells already in place and not constructed to efficiently evaluate sources or loading estimates.

## 12.3 Conclusions

This evaluation provides conclusions that are based on the professional judgment of the project team.

- Groundwater is an important contributor of nutrients to Lake Tahoe.

- The estimated nutrient loading from groundwater to the lake is 50,800 kg (111,995 lbs) for total dissolved nitrogen and 6,800 kg (14,991 lbs) for total dissolved phosphorus. The overall nitrogen and phosphorus loading from groundwater estimated as part of this study is 12% and 15% of the total annual budget for the lake, respectively. This is similar to the estimates developed by Thodal (1997). The nitrogen loading from groundwater is a significant in-basin contributor as the streams and direct runoff were estimated to constitute 20% and 10% of the nutrient loading to Lake Tahoe annually (Murphy et al. 2000). The phosphorus contribution to Lake Tahoe from groundwater estimated in this evaluation, 15% is lower than other sources. The phosphorus loading estimates

presented in Murphy et al. (2000) are 27% atmospheric deposition, 29% stream loading and 34% direct runoff. However, when comparing the dissolved phosphorus groundwater contribution only against other sources, groundwater is a significant contributor of dissolved phosphorus annually. Using the values established in this evaluation, groundwater constitutes 40% of the soluble phosphorus to Lake Tahoe annually. Table 12-2 summarizes the regional and basin-wide groundwater nutrient loading estimates to Lake Tahoe.

**Table 12-2. Regional and Lake Tahoe Basin-Wide Nutrient Loading Estimates Via Groundwater**

| Region | Total GW Nitrogen Loading (kg/year) | Total GW Phosphorus Loading (kg/year) |
|---|---|---|
| South Lake Tahoe/Stateline | 2,459 | 416 |
| East Shore | 6,151 | 140 |
| Incline Village | 4,189 | 768 |
| Tahoe Vista/Kings Beach | 9,667 | 1,099 |
| Tahoe City/West Shore | 28,327 | 4,395 |
| Lake Tahoe Basin-Wide | 50,800 | 6,800 |

- The estimated ambient annual groundwater nutrient loading from is 11,700 kg (25,794 lbs) of total dissolved nitrogen and 4,400 kg (9,700 lbs) of total dissolved phosphorus. This leaves the remaining 39,100 kg of total dissolved nitrogen and 2,400 kg of total dissolved phosphorus coming from other sources.

- The areas potentially contributing the largest annual nutrient loading through groundwater are Tahoe City/West Shore and Tahoe Vista/Kings Beach. The estimates illustrate that the areas deserving additional investigation, characterization and potentially remediation are Tahoe Vista/Kings Beach and Tahoe City/West Shore. This is mostly due to the higher gradients and concentrated development along the lake shore.

- Wells and stream gaging stations within the basin are, for the most part, not surveyed to define an accurate horizontal and vertical position. This introduces errors in determining the hydraulic gradient for each area.

- Subsurface geology is not well defined in the basin. Extensive investigation of the subsurface geology is needed to better understand the aquifer shape, hydraulic conductivity of the aquifer, and depth to bedrock.

- Fracture flow in the basin is not understood. Most studies, including this one, have assumed that fracture flow is insignificant. There have been no studies on the actual flow that could be associated with bedrock fractures.

- There are minimal samples that could be used to characterize background. The natural levels of nitrogen and phosphorus groundwater concentrations are not well understood.

- The monitoring network is not structured to evaluate the difference between shallow and deep nutrient concentrations. This type of evaluation can be done only in localized areas.

- The monitoring network is not structured to evaluate the contributing land uses in the basin. Wells that have been used for monitoring are typically public or private drinking water wells and not specifically designed to evaluate specific land use contributions.

- Phosphorus plumes generated from many sources in the basin may be a continuing problem for years to come. As basin soils become saturated with phosphorus, the nutrient travels more easily to groundwater. Once in the groundwater, the high retardation factor combined with the persistence prove to be a significant problem.

- A rigorous monitoring program would be required to provide significantly better data on regional and basin-wide nutrient loading.

- The evaluation of fertilizer application estimated the total annual nitrogen and phosphorus loading applied in the basin. Total nitrogen estimates ranged from 142,882 kg (157.5 tons) applied annually (Section 10.1). Total phosphorus estimates ranged from 44,996 kg (49.6 tons) applied annually. This shows that the fertilizer used in the basin could be a significant source to the annual nutrient budget to the lake. There are many different factors determining if the nutrients are utilized by the plants for which they're intended or are transported to the groundwater unused. Continuous application of fertilizer over long periods of time could saturate the soil with phosphorus. If this occurred, much of the phosphorus would not be used by the plants, but rather transported to the groundwater zone.

- Sewage is another potential source of nutrients in the groundwater. A study conducted by Camp Dresser and McKee (CDM) for the Corps (USACE 2003) concluded that exfiltration was not a significant source of nutrients to the lake. Using the exfiltration rate and average nutrient concentration of sewage, the annual nitrogen loading rate was estimated to be 1,746 kg (3,850 lbs) per year and the annual phosphorus loading rate was estimated to be 467 kg (1,030 lbs) per year, respectively. Compared to the nutrient loading estimated as part of this study, this constitutes 3.4% and 13.7% of the annual nitrogen and phosphorus loading from groundwater to the lake each year. The effects of decommissioned septic tanks were also evaluated. Based on previous studies, it was estimated that

each septic tank could have contributed between 2.13 to 4.86 kg of phosphorus to the groundwater zone. It's estimated that the phosphorus could take as many as 110 hundred years to travel 500 meters to the lake. This implies that much of the phosphorus in the groundwater as a result of septic tank use could still be a risk to the lake in the future. Conversely, much of the nitrogen has probably already reached the lake as it typically travels at the same rate as groundwater. Septic tank phosphorus plumes may be a continuing problem associated with loading estimates. The high retardation factor associated with phosphorus suggests that much of this nutrient associated with septic tanks has not yet reached the lake and may be a continuing source for a long period of time. Although little information is available for former treated water irrigation areas, these are also potential contributors to nutrients.

- Other potential contributors are engineered infiltration basins. Little data is available to determine the loading estimates to groundwater. There have been no studies linking the surface loading versus groundwater loading estimates. The basins have the potential of concentrating the nutrients and subsequently forming a point source for groundwater contamination.

## 12.4 Recommendations

Based on the findings and conclusions of this study, the following is recommended:

- A comprehensive approach to groundwater monitoring and reporting is recommended to provide consistent and high quality data. Specific areas and sources have been identified as having higher potential for contributing nutrients to the lake through groundwater and should be evaluated for potential remedy. Developing a comprehensive monitoring Work Plan to be used on all nutrient groundwater monitoring activities in the basin is an important first step. This will provide a framework for data quality and consistency. Through this, basin managers will be able to utilize all data gathered in the basin to continue to monitor trends in groundwater quality. This would also include reporting requirements so all data collected in the basin can be easily included in the Tahoe Integrated Information Management System (TIIMS).

- All wells and stream gage stations that are used in the basin as part of the monitoring network in the basin should be surveyed. This is an inexpensive first step in developing more accurate gradients to be used in groundwater flux estimates. All of the surveys should be based on a similar horizontal and vertical coordinate system, relative to mean sea level so all data is directly comparable.

- Investigation of select infiltration basins should be conducted in the short and long term to determine their effects on groundwater.

- Investigation of select septic tanks and former treated wastewater infiltration areas should be conducted to verify the existence of persistent phosphorus plumes and to determine mitigation measures.

- A more detailed groundwater hydrology and nutrient investigation in the Tahoe Vista/Kings Beach and Tahoe City/West Shore areas is warranted, as they appear to be areas of highest nutrient loading to Lake Tahoe through groundwater. With the collection of additional information, groundwater flow models could be developed for the regions to better understand the groundwater/lake interactions and to determine if these initial estimates are close.

- Surface geophysical investigations should be run along key transects both parallel and transverse to the shoreline. These data can be used to better define lateral continuity of major reflecting surfaces. Select, continuously cored test pilot holes should then be drilled to validate material types to ground truth the surface geophysics. Such geophysical surveys should include seismic reflection surveys to define general stratigraphic patterns and the basement geometry. Where shallow stratigraphic information is required, ground-penetrating radar surveys should be conducted to acquire high-resolution information for the upper 60 to 100 ft.

- A follow-up study on the interaction of groundwater with streams should be conducted in the basin. The determination of loading to the streams from groundwater may be an important contributor of nutrients to the lake through surface water.

- It is too early to identify specific areas that could immediately use the nutrient reduction alternatives that could be applied in the basin to aid in reduction of nutrient loading to the lake. There needs to be focused investigations of sources to identify areas that could use these technologies.

- Implementing BMPs should continue, but include groundwater as a component of the decision process for recommending and implementing BMPs.

- Awareness programs to educate the public on how they can reduce nutrient loadings to soil and groundwater in their own backyards should also be continued for the protection of groundwater and surface water quality. Public education about lawn fertilizer application in residential yards and pet dropping pickup in designated pet walking areas can reduce an overlooked yet contributing source of nutrients to groundwater.